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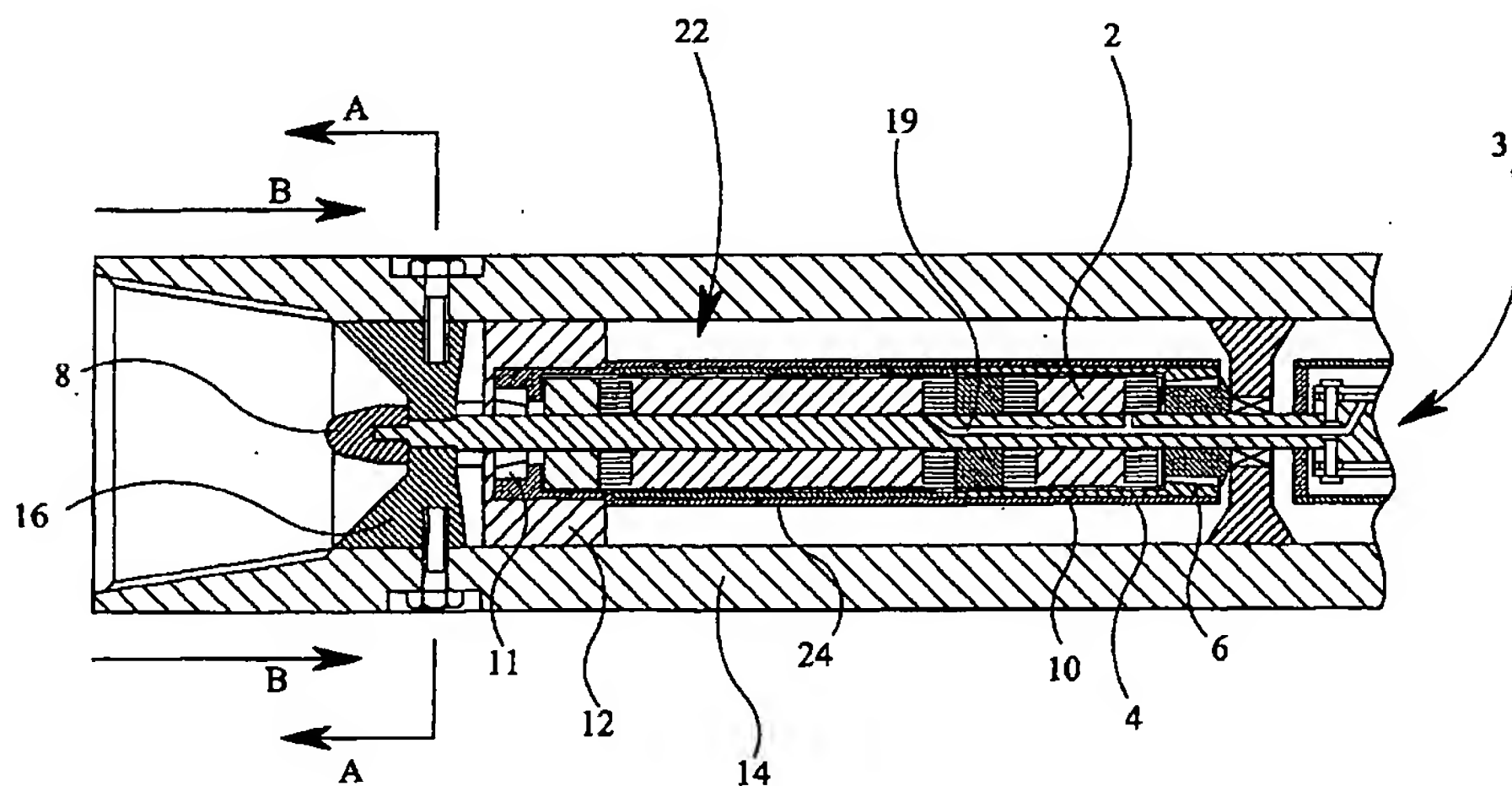
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(54) Title: DOWNHOLE TORQUE-GENERATING AND GENERATOR COMBINATION APPARATUS



(57) Abstract: A combination of a torque-generating apparatus with an alternator/generator. The torque-generating apparatus comprises a first assembly (10, 25) including a generally cylindrical member of magnetically soft material and having a longitudinal axis, and a second assembly (2) arranged coaxially within the first assembly and including an electromagnetic winding (4). The first assembly (10, 25) and the second assembly (2) are rotatable relative to each other about the axis. Relative rotation between the first (10, 25) and second (2) assemblies induces a magnetic field which generates rotational torque between the first and second assemblies. Rectification means (31) is provided to convert alternating current electrical output from the alternator/generator (22) to provide D.C. current to the electromagnetic windings (4) of the torque generating apparatus to generate an electromagnetic braking effect.

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**DOWNHOLE TORQUE-GENERATING AND GENERATOR COMBINATION APPARATUS**

This invention relates to a combination of a torque-  
5 generating apparatus with a generator/alternator. More particularly, but not exclusively, the invention relates to such a combination for down hole use in drilling applications.

10 The presently preferred power generator in oilfield exploration or extraction applications is the mud alternator because it is powerless on the surface, and therefore safe to handle, and only generates power once down hole and spinning in the mud flow. However, one of the major problems faced by  
15 both the provider and end-user of drilling equipment has been the control of impeller speed of down hole mud alternators.

All mud alternators effectively run open loop and the only way to govern their speed is either to modify the flow rate  
20 of mud pumped past the impeller or to change the impeller. These methods are not always successful in controlling alternator speed and, hence, power output. An alternator that rotates too quickly generates too much voltage for the down hole apparatus and consequently causes the apparatus to  
25 overheat. If an alternator causes the apparatus to overheat for too long, the apparatus is likely to fail resulting in a costly interruption of the drilling programme. A loss of down hole power results in a loss of communication with the drilling apparatus and the entire drill string must be pulled  
30 from the well to effect repairs. For an extended reach hole, the extraction, repair and replacement can take in excess of two days and a drilling engineer therefore avoids excessive rotation speeds for the alternator if at all possible.

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To ensure the alternator is always operated within safe limits, the alternator RPM or output voltage is transmitted to the surface at frequent intervals in order that the drilling engineer may monitor the performance of the alternator and effect alternator speed corrections by adjusting the mud pumping rate.

The preferred method for avoiding excessive rotation speed for the alternator is to select a suitable impeller for the alternator during the planning stage of a drilling contract. Mud flow rates can vary widely, for example from 150 to 800 United States gallons per minute. One of the planning tasks is to establish the minimum and maximum mud flow rates for the task in order that an optimum impeller can be selected. The difficulty with this method is that an incorrect impeller is sometimes fitted to the alternator. The drilling engineer is then faced with the decision of not using the drilling apparatus until the correct impeller has been fitted, or risking damage to the drilling apparatus due to excessive alternator power output.

There is therefore a requirement to be able to control alternator speed in order to avoid excessive power outputs.

Furthermore, present apparatus is vulnerable to the aggregation of mud and debris leading to clogging of the machinery and down hole failure.

It is an object of the present invention to provide a combination of a torque generating apparatus with an alternator/generator capable of fulfilling at least some of the above requirements.

According to the present invention there is provided a combination of a torque-generating apparatus with an

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alternator/generator, the torque-generating apparatus comprising: a first assembly including a generally cylindrical member of magnetically soft material and having a longitudinal axis, a second assembly arranged coaxially within the first assembly and including an electromagnetic winding, the first assembly and the second assembly being rotatable relative to each other about the axis, the arrangement being such that relative rotation between the first and second assemblies induces a magnetic field which generates rotational torque between the first and second assemblies, and characterised in that rectification means is provided to convert alternating current electrical output from the alternator/generator to provide D.C. current to the electromagnetic windings of the torque generating apparatus to generate an electromagnetic braking effect.

A "magnetically soft material" is a material which is not capable of being substantially permanently magnetised, but which becomes magnetised whilst in an externally applied magnetic field.

The first assembly may be a rotor assembly of the apparatus for producing rotational torque and the second assembly may be a stator assembly of the torque generating apparatus.

The second assembly may comprise a magnetically soft steel.

The first and second assemblies may be separated by a narrow gap.

The first assembly may be disposed so as substantially to surround the second assembly.

The first assembly may be substantially solid or may be formed from a plurality of laminations.

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The second assembly may be substantially solid or may be formed from a plurality of laminations.

5 A number of generally longitudinal grooves may be provided to the inside surface of the cylindrical member of the first assembly. The grooves may be substantially coaxial with the longitudinal axis of the first assembly. Alternatively, the grooves may be provided so as to form at least a partial helix around the longitudinal axis of the first assembly.

10

The second assembly may be provided with a number of pole pieces extending generally radially from the longitudinal axis thereof. The pole pieces of the second assembly may be provided with an electromagnetic winding, adjacent poles  
15 being magnetisable in opposite directions. Means may be provided to control the degree of the magnetisation. Gaps between the pole pieces may be filled with a potting material. The surface of the second assembly may be covered with a layer of soft magnetic or non-magnetic material.

20

The first assembly may be provided with external rotation means such as impeller means adapted to rotate the first assembly, the impeller means being adapted to be disposed in use within a moving fluid, the motion of the fluid acting  
25 upon the impeller means so as to rotate the first assembly.

The torque-generating apparatus and the alternator/generator may be provided on a common shaft.

30 The alternator/generator may be provided with external rotation means, such as impeller means adapted to rotate the alternator/generator, the impeller means may be adapted to be disposed in use within a moving fluid, the motion of the fluid acting upon the impeller means so as to rotate the

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alternator/generator. The impeller means may be an integral part of a magnet carrier of the alternator/generator.

5 The electrical output of the alternator/generator may be connected directly to the electromagnetic winding of the torque-generating apparatus or may be connected indirectly by way of alternator voltage regulation means to create the electromagnetic braking effect.

10 Where the electrical power of the alternator/generator is connected directly to the electromagnetic winding of the torque-generating apparatus, the electromagnetic braking effect may be modified by varying the resistance of the winding, for example with one or more external resistances or  
15 by changing the gauge of the winding wire, or by varying the gap between the first and second assemblies of the torque-generating apparatus.

Where the electrical output of the alternator/generator is  
20 connected indirectly to the electromagnetic winding of the torque-generating apparatus, the alternator voltage regulation means may function to provide a progressive braking effect and/or to effect braking at a predetermined set point. The predetermined set point may be determined by  
25 the voltage output of the alternator/generator. The predetermined set point may be variable.

For a better understanding of the present invention and to show more clearly how it may be carried into effect,  
30 reference will now be made, by way of example, to the accompanying drawings which show schematically various embodiments of the present invention. The figures may not be to scale. In the drawings:



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Figure 1 is a cross-sectional view of an embodiment of a combination according to the present invention;

Figure 2 is an end view of the combination of Figure 1  
5 looking in the direction of the arrow B;

Figure 3 is a cross-sectional view of the combination of Figure 1 taken along the line A-A;

10 Figure 4 is a more detailed view of a stator shown in Figure 1;

Figure 5 shows two views of a stator pole piece;

15 Figure 6 is a cross-section of the stator shown in Figure 4;

Figure 7 is an end view of the stator shown in Figure 4;

Figure 8 is a sectional view of a rotor shown in Figure 1;  
20

Figure 9 is an end view of the rotor of Figure 8;

Figure 10 is an end view detail of the rotor and stator assembly;  
25

Figure 11 is a cross-sectional view of another embodiment of a rotor similar to that shown in Figure 1 showing a laminated structure;

30 Figure 12 is an end view of the rotor of Figure 11;

Figure 13 is an end view detail of a rotor and stator assembly incorporating the rotor of Figures 11 and 12;

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Figure 14 is a schematic drawing of a rectifying means used in the combination of Figure 1; and

Figure 15 is a schematic drawing of an alternative  
5 rectifying means incorporating an alternator voltage regulator device used in the combination of Figure 1.

Figure 1 shows a combination of a torque generating apparatus and alternator/generator suitable for use in drilling  
10 apparatus. The torque generating apparatus comprises a second assembly in the form of a cylindrical stator 2. The stator 2 is shown in more detail in Figures 4 to 7. The stator is made of magnetically soft material and is provided with stator windings 4 arranged so that, when energised, the  
15 stator 2 is magnetised as discussed below. The stator is mounted on a fixed shaft 8. Surrounding the stator is a first assembly in the form of a magnetically soft steel rotor 10. The rotor 10 is mounted on the stator 2 by way of bearings 6, 11, such as thrust bearings. The rotor/stator  
20 assembly is contained within a cylindrical housing 14 which may typically be a section of drill collar. The assembly is supported by an anchor 16 which is bolted to the housing.

A three phase alternator 22 is provided on the same shaft as  
25 the torque-generating apparatus. The alternator 22 and the torque-generating apparatus share a common rotor.

The output voltage of the alternator is connected via rectification means 31 to the torquer stator windings so that  
30 the torquer provides negative feedback in the form of progressive braking as the rotational speed of the joint rotor assembly increases or when the rotational speed of the rotor exceeds a predetermined limit.



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The stator windings 4 of the torque generating apparatus are connected to windings of the alternator by way of access holes 19 formed in the core of each apparatus as shown in Figure 1.

5

In use, the combination is disposed down hole, drilling mud being pumped down the hole in the direction indicated. The moving drilling fluid acts on the impeller 12 so as to rotate the rotor 10.

10

Mud alternators, such as the illustrated alternator 22, are generally three phase electrical rotating machines connected to a full wave rectifier 31 to convert the three alternating current waveforms into a single direct current supply. A typical circuit diagram is shown in Figure 14. The impeller 12 is an integral part of a magnet carrier 24 of the alternator and spins at several thousand rpm in response to the flow rate of mud past the impeller. By electrically connecting the rectified output of the alternator 22 to the stator windings 4 of the torque-generating apparatus, an electromagnetic brake is created between the torque-generating apparatus and the alternator. Depending on the manner of the electrical connection, two different braking effects can be created as will be explained in more detail hereinafter.

25

Electrically connecting the stator windings 4 of the torque generating apparatus to the rectified output of the alternator 22 creates a progressive braking effect because the alternator 22 progressively energises the stator windings 4 with current. The greater the rectified alternator voltage, the greater the current flowing in the stator windings 4 and the greater the electromagnetic braking effect. The feedback loop created provides proportional control over the alternator output and the maximum speed of

35

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the alternator 22 is controlled irrespective of the profile of the impeller 12 and the mud flow rate. Such an electrical connection provides the more simple method of speed control within the alternator assembly and may be fine-tuned by  
5 varying either the resistance of the stator windings or the air/mud gap between the rotor and stator of the torque-generating apparatus. The resistance of the stator windings 4 may be modified by adding external resistors in series with the stator windings, or by changing the gauge of wire used to  
10 construct the stator windings. The total resistance, and hence the braking control achieved by either method, may be determined by calculation. Changing the air/mud gap involves a grinding operation to increase the gap between the rotor and stator of the torque-generating apparatus to reduce the  
15 braking effect.

Alternatively, as shown in Figure 15, the braking characteristics may be changed from proportional to any other form of control by providing an alternator voltage regulator  
20 device 33 between the alternator 22 and the torque-generating apparatus. A switch mode controller is preferred to minimise losses within the alternator voltage regulator device and offers the possibility of dynamically changing the speed characteristics down hole via mud pulse telemetry.

25 An alternator voltage regulator device can be used to apply both linear and/or non-linear braking characteristics to the alternator by way of the stator windings of the torque-generating apparatus. A typical circuit, shown in Figure 15, comprises an alternator voltage regulator in the form of a  
30 programmable switch mode power supply deriving power from the rectified alternator output and supplying programmed power output to the stator windings 4 of the torque-generating apparatus. A predetermined or programmable voltage-sensitive  
35 trip device activates the switch mode power supply. Below

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the trip point, the alternator runs open loop and there is no induction braking. Above the trip point, the loop is closed and induction braking is applied to the alternator. In this manner the set point between open loop and closed loop  
5 control can be programmed at any chosen location on the alternator speed curve and may be tuned to vary the output voltage according to the requirements of different customers.

By coupling the alternator to a torque-generating apparatus,  
10 the alternator no longer operates open loop and can safely be left unattended down hole to monitor its own output. Manufacturers of down hole alternators need only provide one system for all customers instead of several  
15 impeller/alternator pairs for differing output power demands and variable mud flow rates. A single combined alternator and torque-generating apparatus may be programmed to reproduce the output power profiles corresponding to  
20 different impellers by limiting the output power with induction braking. Such an arrangement reduces design and manufacturing costs, simplifies the operational needs of field engineers, and improves down hole reliability of the alternator and down hole instrumentation.

Figure 2 is an end view of the apparatus of Figure 1. It  
25 shows the fixed shaft 8, anchor 16 and the impeller blades 12. The direction of mud flow in Figure 2 is into the paper, causing rotation of the impeller blades.

Figure 3 shows a cross-sectional view as indicated in Figure  
30 1. The assembly anchor 16 is shown in cross-section, bolted to the drill collar housing. The shaft 8 can be seen in cross-section. The view in Figure 3 is looking inwards into the assembly in the direction of the incoming mud, and the impeller blades 12 can be seen behind the assembly anchor 16.

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Figures 4 to 7 are more detailed views of the stator assembly. The stator 2 of the torque generating apparatus is a simple four-pole electromagnet which forms the electrical and mechanical centre of the machine. The stator 2 has a central shaft from which radially project four pole pieces 35, as shown. The number of pole pieces need not be limited to four - any suitable number of pole pieces may be provided, larger machines requiring more pole pieces.

10 To prevent the stator 2 from being crushed by normal down hole drilling pressures, the gaps between the stator pole pieces may be filled with a high compressive strength material such as epoxy filler (not shown). This allows the stator 2 to maintain its shape and survive pressures in  
15 excess of 20,000 pounds per square inch.

The stator 2 of the torque generating apparatus is wound with high-temperature-resistant enamelled copper wire (not shown in Figures 4 to 7) so as to produce alternate north and south magnetisation of the pole pieces. To preserve the integrity of the stator winding from the drilling mud, as shown in Figures 1 and 10 a thin sleeve of soft magnetic or non-magnetic material 21 is machined to cover the stator windings. End cheeks provided on the stator receive the  
25 sleeve 21 and are welded thereto to seal the assembly. This seals the edges of the stator 2 and protects the contents from contamination. The covering, for example in the form of a cylinder, allows the stator poles to rotate with respect to the rotor 10 whilst maintaining close magnetic contact. A  
30 small magnetic gap is required to create the high output torque reactions from this machine.

An important feature of the apparatus is the use of electromagnetic advantage to minimise the power demands of  
35 the stator 2. By its nature, this induction machine relies

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upon high rates of change of magnetic flux to effect braking in the rotor. High operating efficiency will therefore be achieved at high rotor RPM.

- 5 Figures 8 to 10 show the rotor 10 of the torque generating apparatus in more detail. The rotor 10 consists of a simple steel cylinder having grooves 20 machined to the inside surface. The grooves 20 perform two important functions. They allow the rotor 10 and stator 2 to maintain close  
10 magnetic contact and at the same time allow a sufficient flow of drilling mud through the annular space between the rotor and stator. This aids lubrication of the rotor bearings 6 and 11 and allows dissipation of heat.
- 15 The grooves 20 also prevent mud particles from aggregating within the annular space and clogging the apparatus. If the annular space were too small, mud particles would become trapped due to low mud-flow velocities. The mud particles would quickly aggregate, binding the stator 2 and rotor 10  
20 and causing a down hole failure. In conventional down hole electrical apparatus, like alternators, which use a permanent magnet rotor, failure frequently occurs due to mud material becoming trapped and clogged within the space between the rotor and stator. The clogging problem is compounded by both  
25 soft and hard magnetic particles that circulate within the mud. Once trapped by the strong magnetic fields within the permanent magnet rotor, the magnetic particles capture non-magnetic mud particles, accelerating clogging. The present apparatus avoids this type of failure by providing a more  
30 generous space between rotor and stator (due to the grooves) in the area of the torquer and by being composed of soft magnetic material which does not trap particles to the same extent as a permanent magnet.

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An important feature of the torque generating apparatus is the use of electromagnetic advantage and a rotor 10, preferably solid, to dissipate waste heat from work done by the apparatus. The induced currents circulating in the rotor  
5 10 would give rise to  $I^2R$  heating in the rotor raising its working temperature. However, because the rotor 10 is manufactured from a magnetically soft material, its performance is unaffected by this temperature rise. It can therefore operate in temperatures much higher than the  
10 current limit of 180 C, without any loss of performance. In theory, the rotor 10 alone can operate at temperatures up to the Curie temperature of the permanent magnets.

According to another realisation of the rotor 10 of the  
15 torque generating apparatus, not shown in the figures, the grooves 20 are formed with a small flute or spiral twist along their length. In this way, every rotation of the rotor 10 produces a small pumping effect, pumping mud and contaminant particles through the apparatus. These features  
20 would expel hard and soft magnetic particles which would otherwise become trapped by the permanent magnets of the alternator windings.

The pole pieces of the stator 2 and the protruding portions  
25 of the rotor inner surface are disposed so as to correspond, being aligned (in the case of a four-pole apparatus) every quarter turn of the rotor 10. As discussed, the number of pole pieces and protruding portions may be varied to suit a particular application. Although the rotor 10 and stator 2  
30 in this example are formed of magnetically soft steel, any suitable soft magnetic material may be employed. Similarly, the protective coating of the stator 2 may be made of ferrous or non-ferrous material.



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Normal use of the torque generating apparatus may erode the inner surface of the rotor 10 and/or the protective coating of the stator 2. This would cause a gradual loss of output torque. The apparatus is, however, easy and economical to  
5 repair, as any mechanical errors may be easily corrected by welding, machining and/or grinding the relevant part.

Figures 11 to 13 show an alternative rotor 25 in more detail. The rotor 25 consists of a laminated steel cylinder having a  
10 number of conductors 29 running the length of the rotor 25. The conductors 29 are connected at each end of the rotor 25 by means of a conductor end cap 27. The arrangement of conductors 29 and end caps 27 form what is known as a squirrel cage conductor winding.

15

The conductors 29 and conductor end caps 27 consist of rods and plates of beryllium copper, which has a similar electrical resistivity to aluminium but is a stronger material, resistant to mechanical abrasion and chemical  
20 attack from drilling muds.

A close magnetic contact is still maintained between the rotor 25 and the stator 2.

25 It should be understood that the stator which can be in a solid or laminated form can be used in conjunction with either a solid or laminated rotor.

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## CLAIMS

1. A combination of a torque-generating apparatus with an alternator/generator, the torque-generating apparatus  
5 comprising: a first assembly (10, 25) including a generally cylindrical member of magnetically soft material and having a longitudinal axis, a second assembly (2) arranged coaxially within the first assembly and including an electromagnetic winding (4), the first assembly (10, 25) and the second  
10 assembly (2) being rotatable relative to each other about the axis, the arrangement being such that relative rotation between the first (10, 25) and second (2) assemblies induces a magnetic field which generates rotational torque between the first and second assemblies, and characterised in that  
15 rectification means (31) is provided to convert alternating current electrical output from the alternator/generator (22) to provide D.C. current to the electromagnetic windings (4) of the torque generating apparatus to generate an electromagnetic braking effect.
- 20
2. A combination as claimed in claim 1, characterised in that the first assembly is a rotor assembly (10, 25) of the torque generating apparatus for producing rotational torque and the second assembly (2) is a stator assembly of the  
25 torque generating apparatus.
3. A combination as claimed in claim 1 or 2, characterised in that the second assembly (2) comprises a magnetically soft steel.
- 30
4. A combination as claimed in any preceding claim, characterised in that the first (10, 25) and second assemblies (2) are separated by a narrow gap.

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5. A combination as claimed in any preceding claim, characterised in that the first assembly (10, 25) is disposed so as substantially to surround the second assembly (2).
- 5 6. A combination as claimed in any preceding claim, characterised in that the first assembly is substantially solid (10) or is formed from a plurality of laminations (25).
7. A combination as claimed in any preceding claim,  
10 characterised in that the second assembly (2) is substantially solid or is formed from a plurality of laminations.
8. A combination as claimed in any preceding claim,  
15 characterised in that a number of generally longitudinal grooves (20) are provided to the inside surface of the cylindrical member of the first assembly (10).
9. A combination as claimed in claim 8, characterised in  
20 that the grooves (20) are substantially coaxial with the longitudinal axis of the first assembly (10).
10. A combination as claimed in claim 8, characterised in that the grooves (20) are provided so as to form at least a  
25 partial helix around the longitudinal axis of the first assembly (10).
11. A combination as claimed in any preceding claim, characterised in that the second assembly (2) is provided  
30 with a number of pole pieces extending generally radially from the longitudinal axis thereof.
12. A combination as claimed in claim 11, characterised in that the pole pieces of the second assembly are provided with

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an electromagnetic winding, adjacent poles being magnetisable in opposite directions.

13. A combination as claimed in claim 11 or 12,  
5 characterised in that means is provided to control the degree of the magnetisation.

14. A combination as claimed in any one of claims 11 to 13,  
characterised in that gaps between the pole pieces are filled  
10 with a potting material.

15. A combination as claimed in any one of claims 11 to 14,  
characterised in that the surface of the second assembly (2)  
is covered with a layer of soft magnetic or non-magnetic  
15 material (21).

16. A combination as claimed in any preceding claim,  
characterised in that the first assembly (10, 25) is provided  
with external rotation means (12) adapted to rotate the first  
20 assembly (10, 25).

17. A combination as claimed in claim 16, characterised in  
that the external rotation means comprises impeller means  
(12).  
25

18. A combination as claimed in claim 17, characterised in  
that the impeller means (12) is adapted to be disposed in use  
within a moving fluid, the motion of the fluid acting upon  
the impeller means so as to rotate the first assembly.  
30

19. A combination as claimed in any preceding claim,  
characterised in that the torque-generating apparatus and the  
alternator/generator (22) are provided on a common shaft (8).

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20. A combination as claimed in any preceding claim, characterised in that the alternator/generator (22) is provided with external rotation means (12).

5 21. A combination as claimed in claim 20, characterised in that the external rotation means comprises impeller means (12) adapted to rotate the alternator/generator (22).

10 22. A combination as claimed in claim 21, characterised in that the impeller means (12) is adapted to be disposed in use within a moving fluid, the motion of the fluid acting upon the impeller means (12) so as to rotate the alternator/generator (22).

15 23. A combination as claimed in claim 21 or 22, characterised in that the impeller means (12) is an integral part of a magnet carrier of the alternator/generator (22).

20 24. A combination as claimed in any preceding claim, characterised in that the electrical output of the alternator/generator (22) is connected directly to the electromagnetic winding (4) of the torque-generating apparatus to create the electromagnetic braking effect.

25 25. A combination as claimed in claim 24, characterised in that the electromagnetic braking effect can be modified by varying the resistance of the electromagnetic winding (4).

30 26. A combination as claimed in claim 25 characterised in that the resistance of the electromagnetic winding (4) can be modified by varying the resistance of the electromagnetic winding (4) with one or more external resistances.

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27. A combination as claimed in claim 25, characterised in that the resistance of the electromagnetic winding (4) can be modified by changing the gauge of the winding wire.
- 5 28. A combination as claimed in claim 24, characterised in that the electromagnetic braking effect can be modified by varying the gap between the first (10, 25) and second (2) assemblies of the torque-generating apparatus.
- 10 29. A combination as claimed in any one of claims 1 to 23, characterised in that the electrical output of the alternator/generator (22) is connected indirectly to the electromagnetic winding (4) of the torque-generating apparatus by way of alternator voltage regulation means to  
15 create the electromagnetic braking effect.
30. A combination as claimed in claim 29, characterised in that the alternator voltage regulation means functions to provide a progressive braking effect.
- 20 31. A combination as claimed in claim 29, characterised in that the alternator voltage regulation means functions to effect braking at a predetermined set point.
- 25 32. A combination as claimed in claim 31, characterised in that the predetermined set point is determined by the voltage output of the alternator/generator (22).
- 30 33. A combination as claimed in claim 32, characterised in that the predetermined set point is variable.



FIG 1

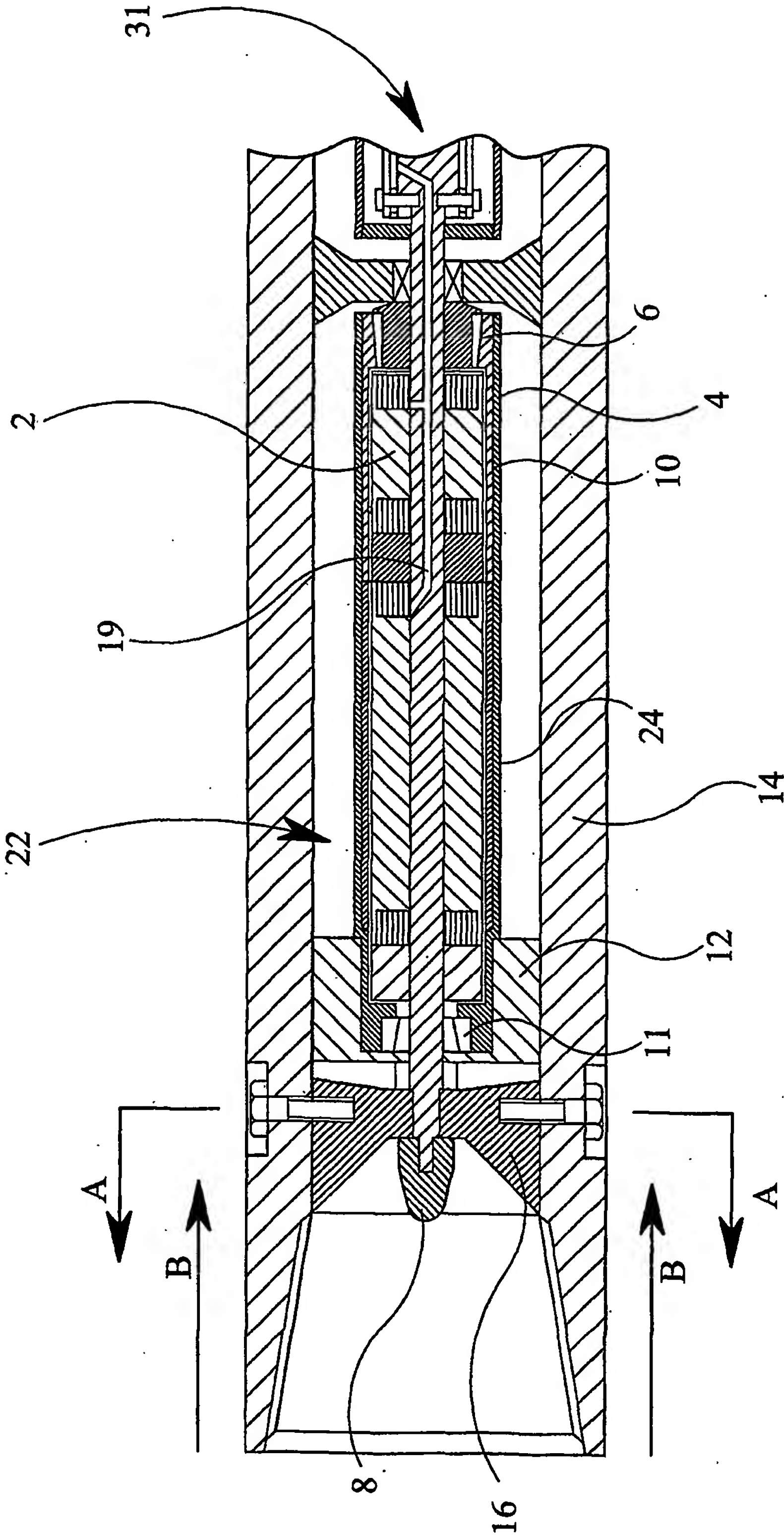


FIG 2

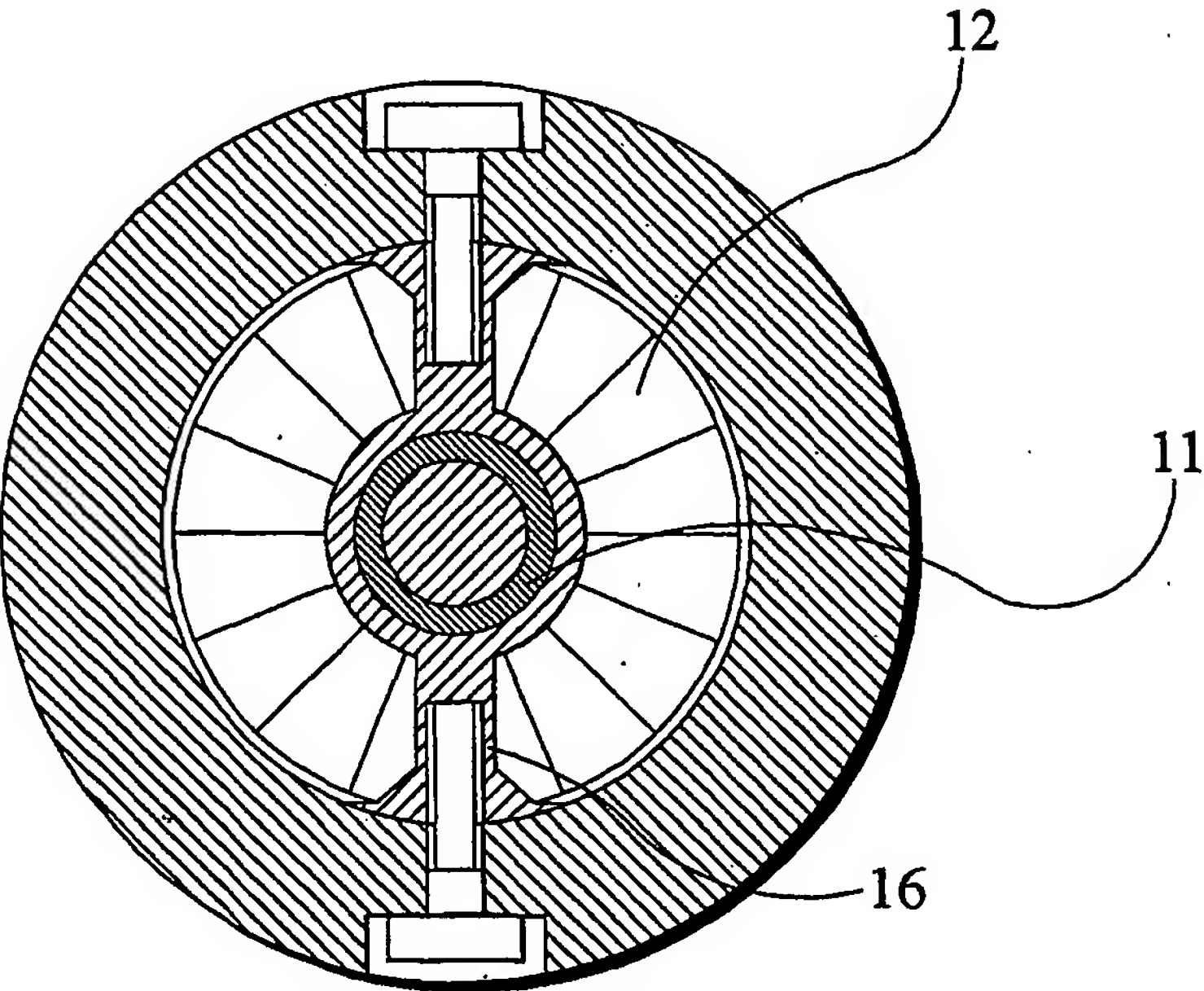
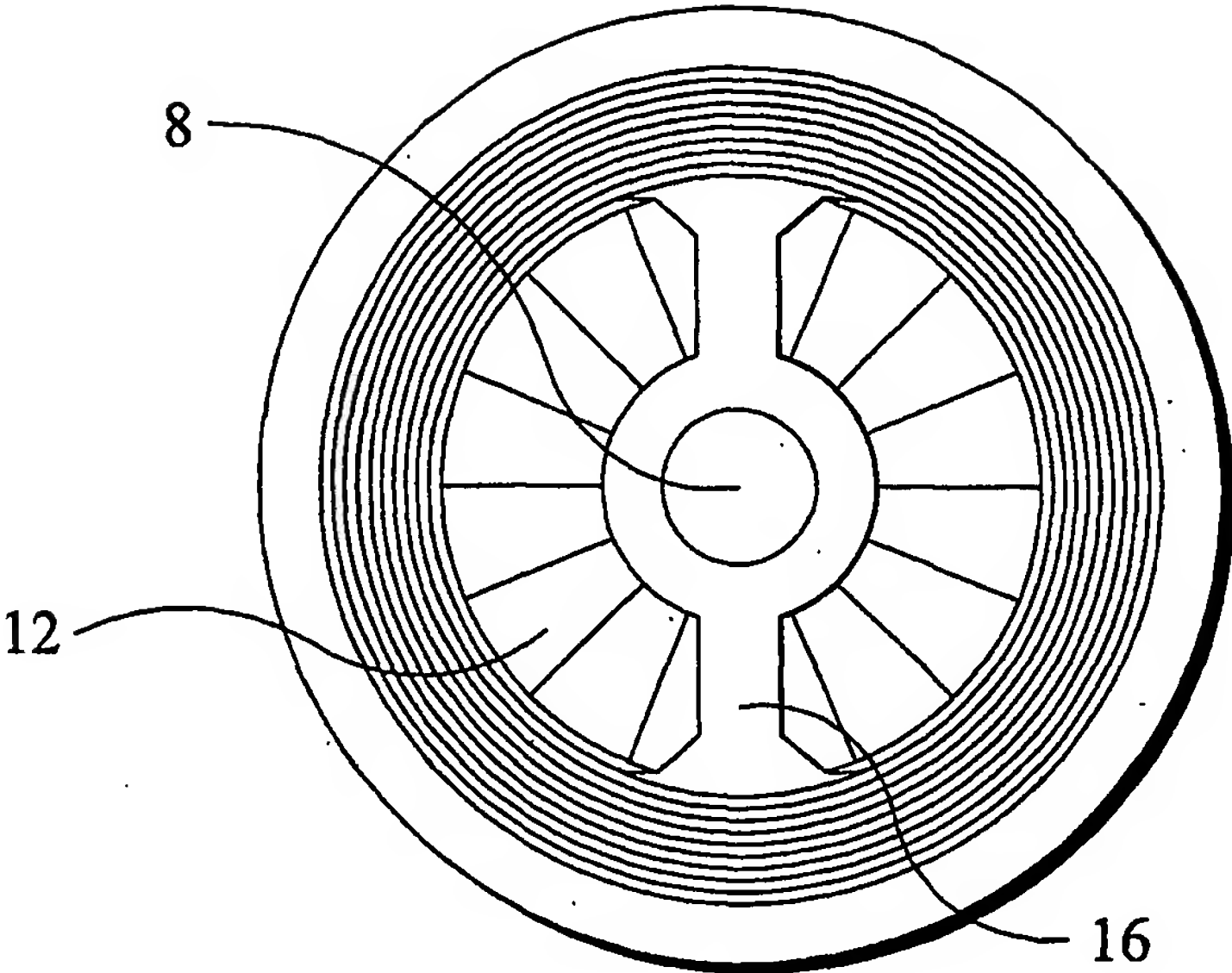


FIG 3

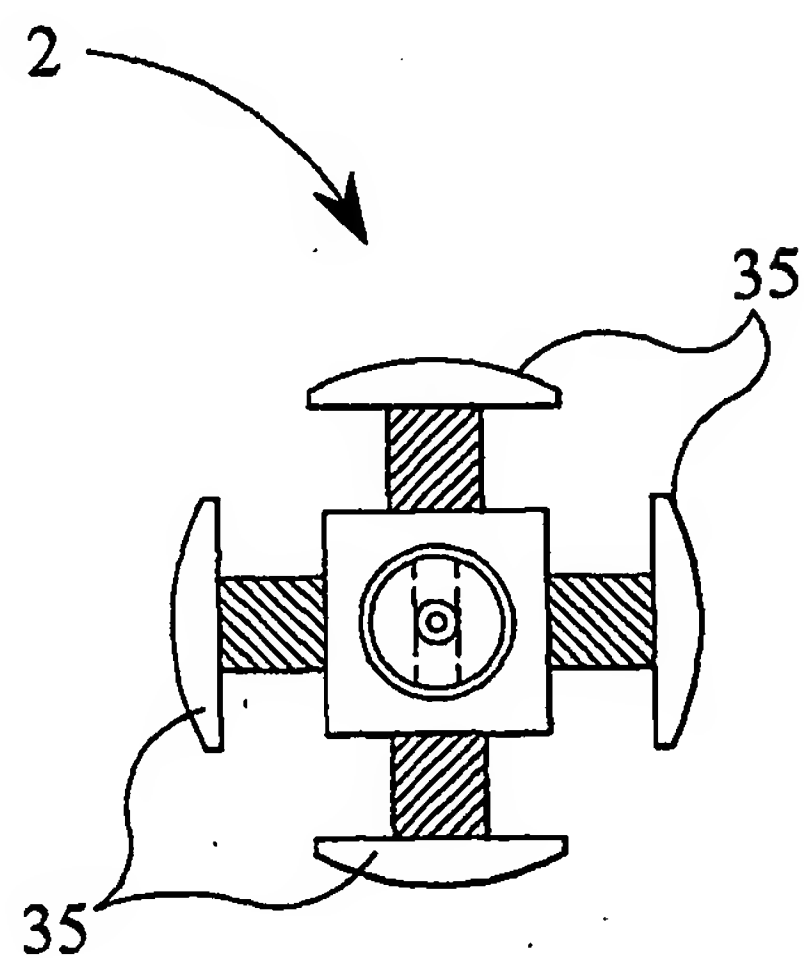
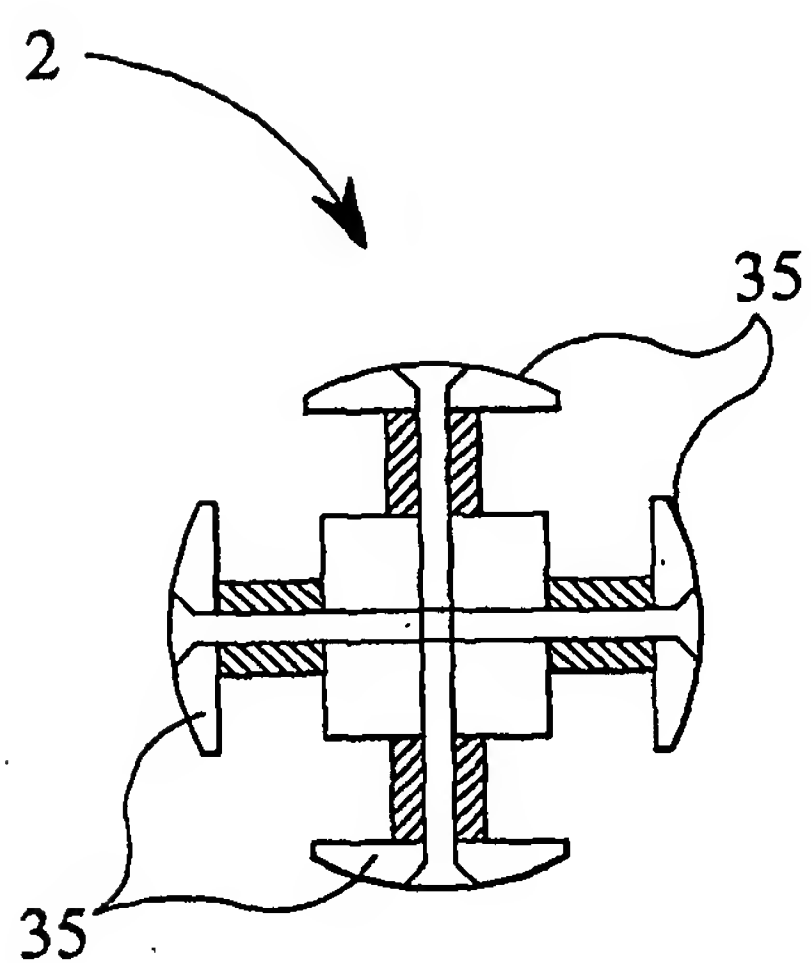
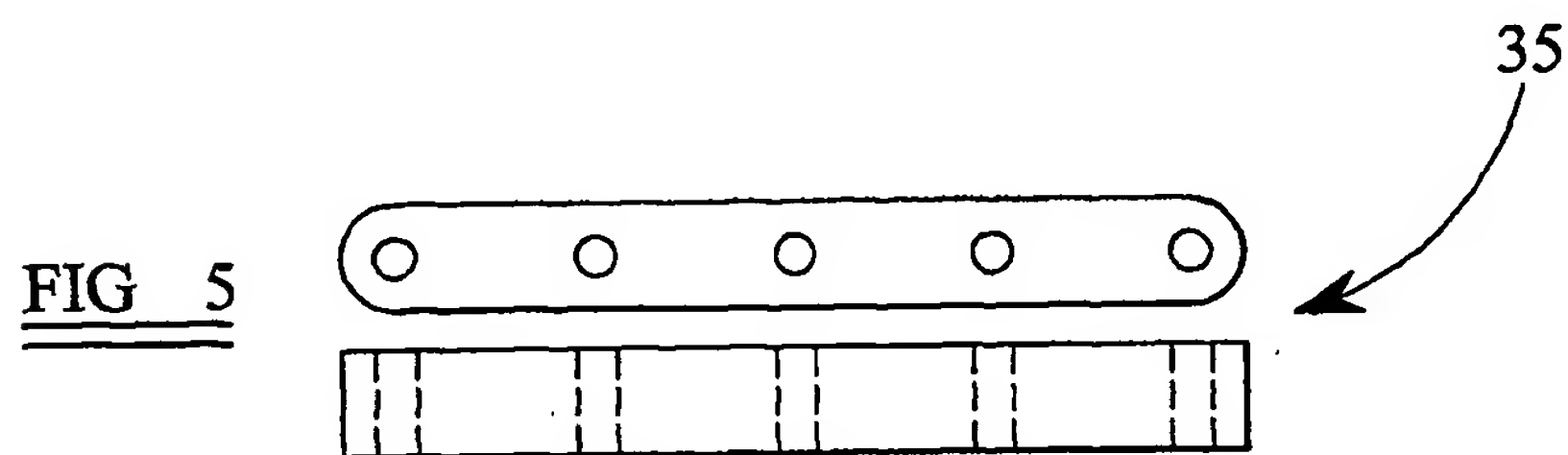
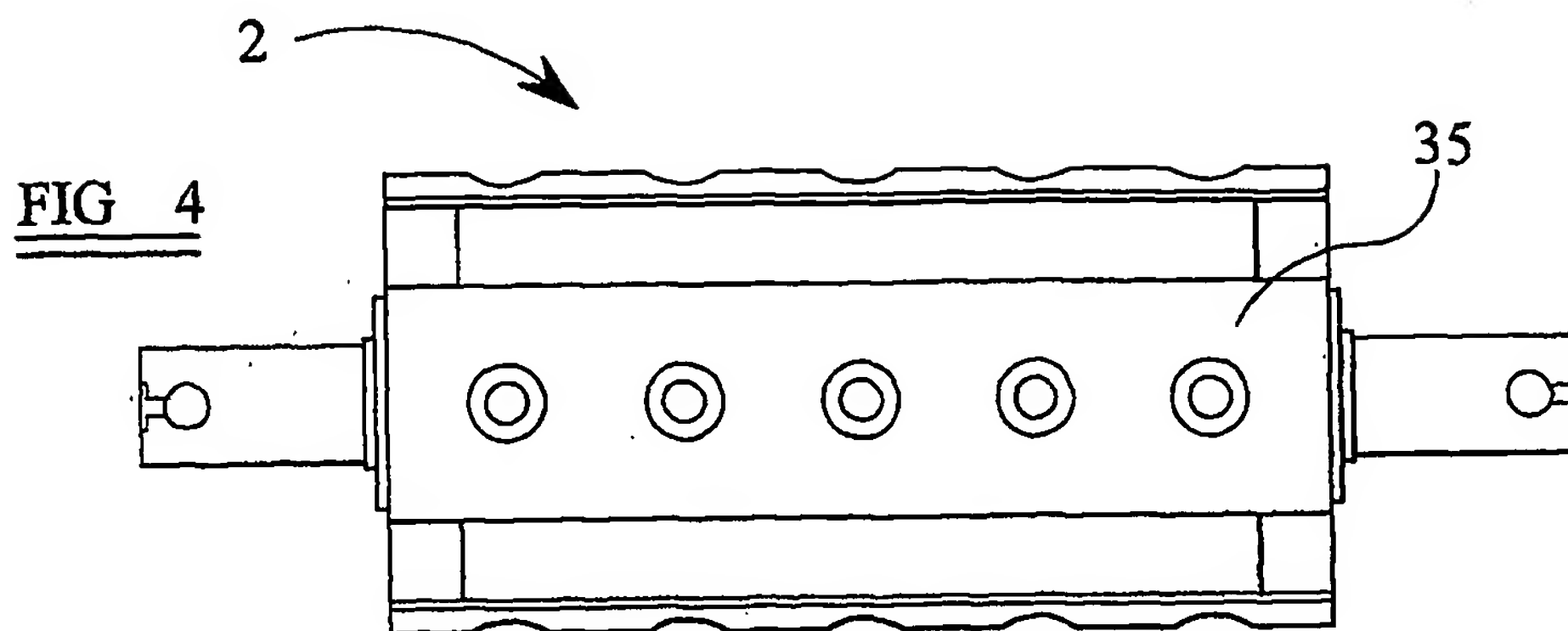


FIG 8

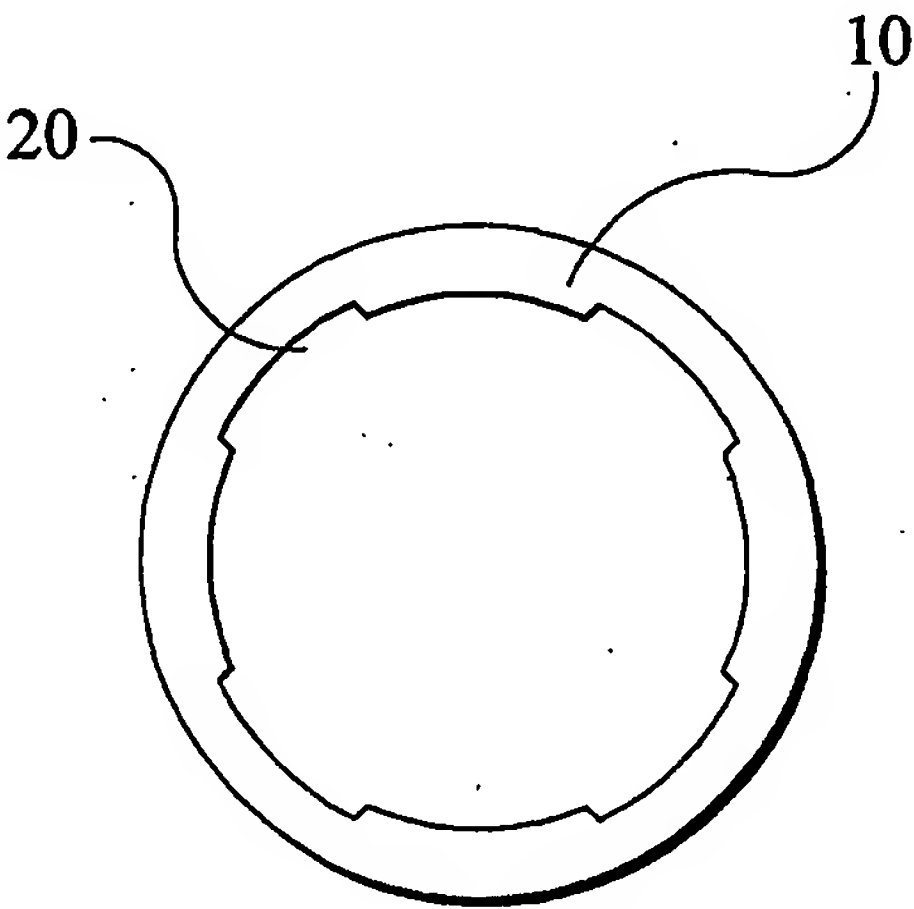
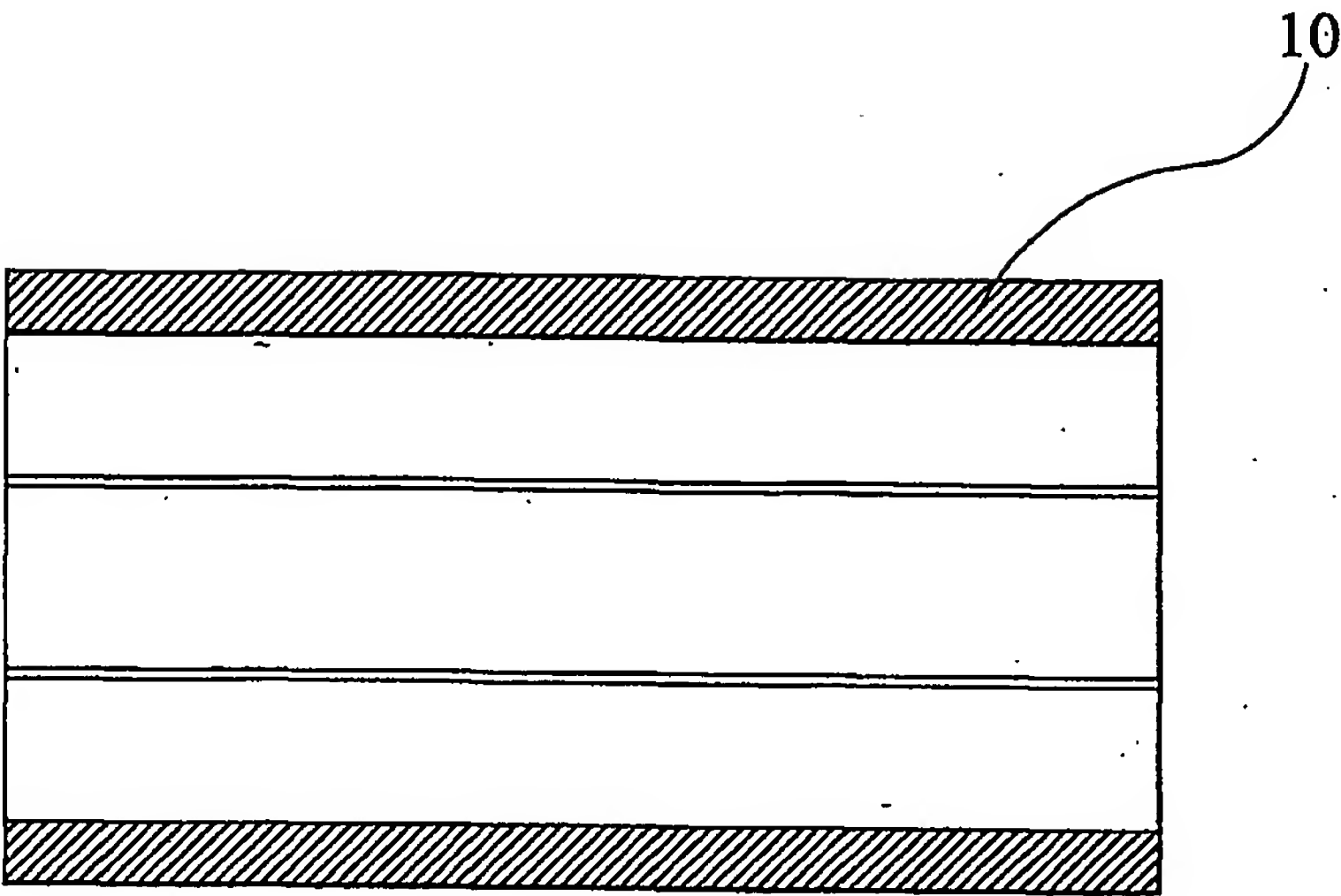


FIG 9

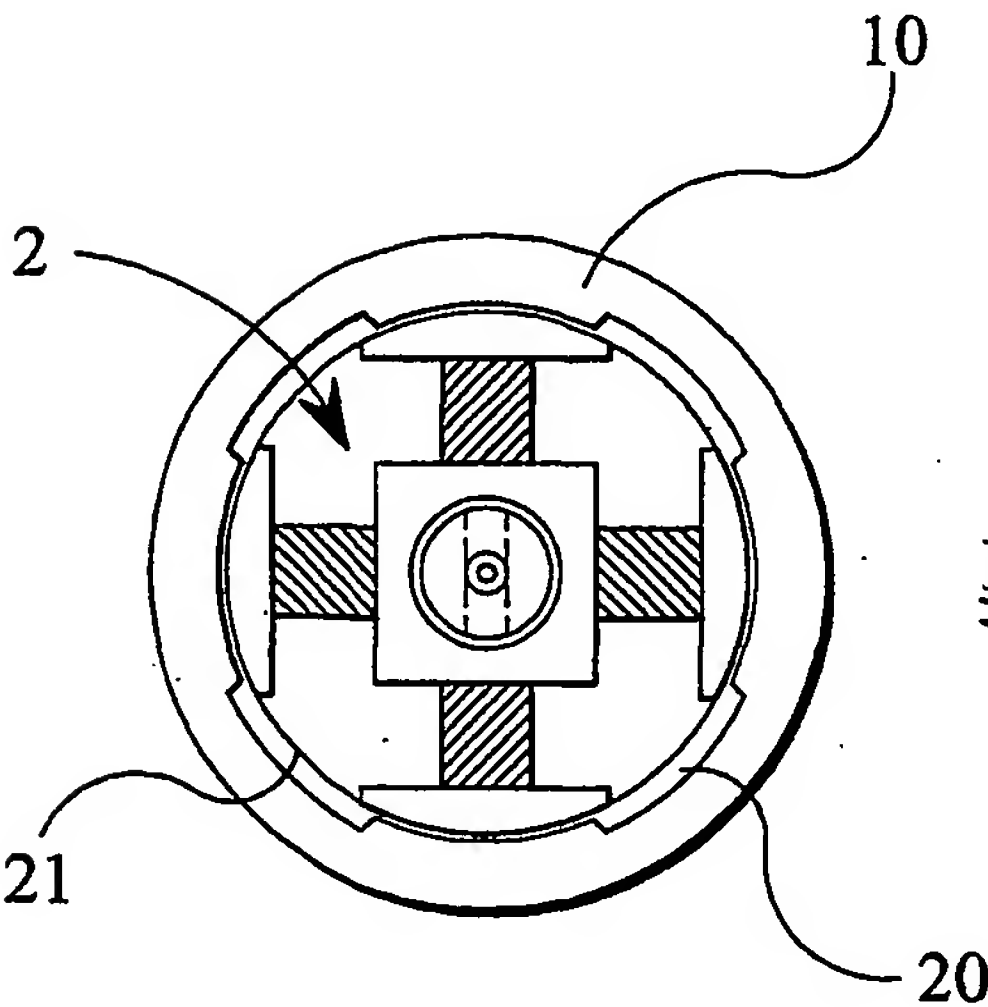
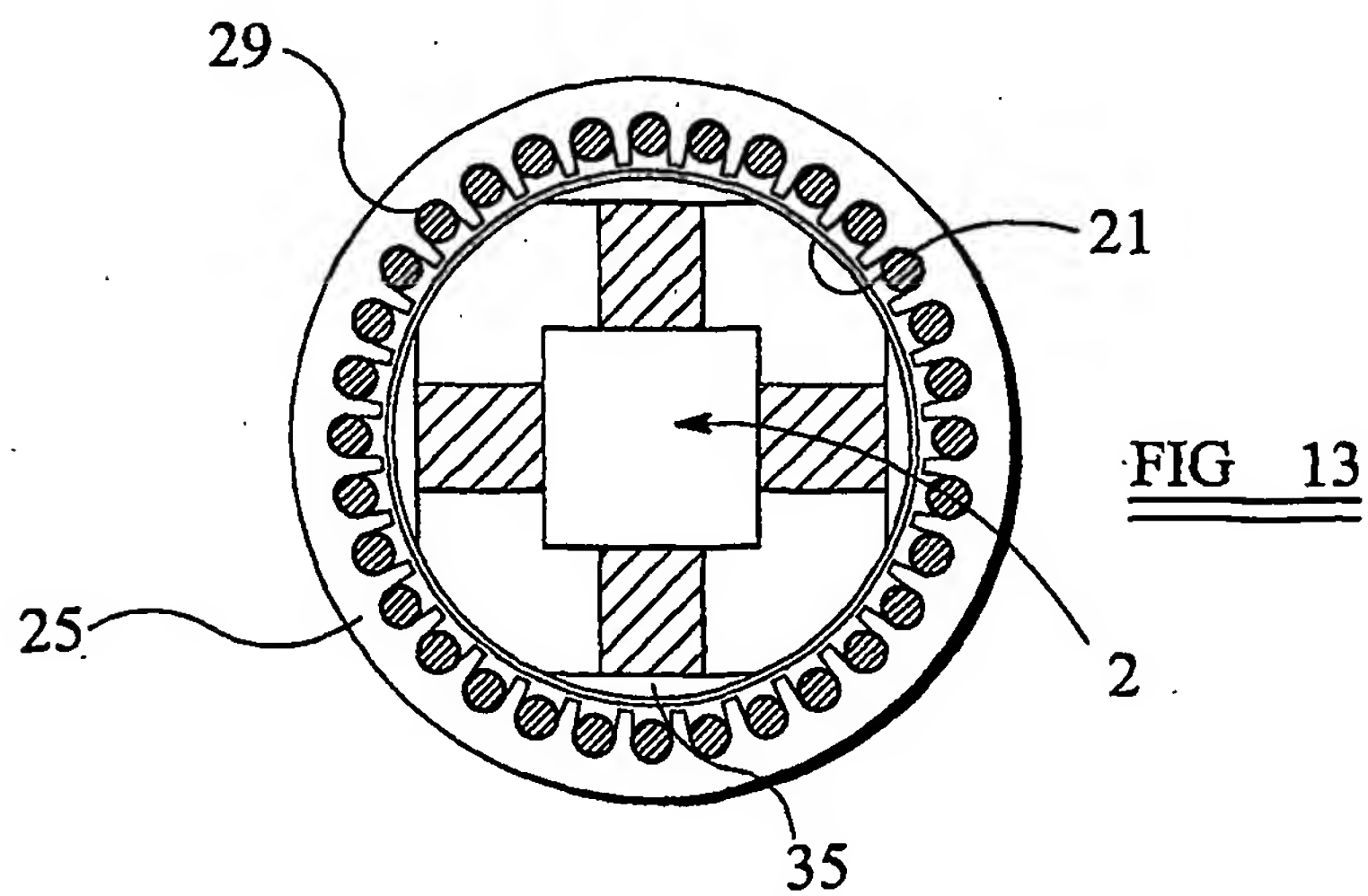
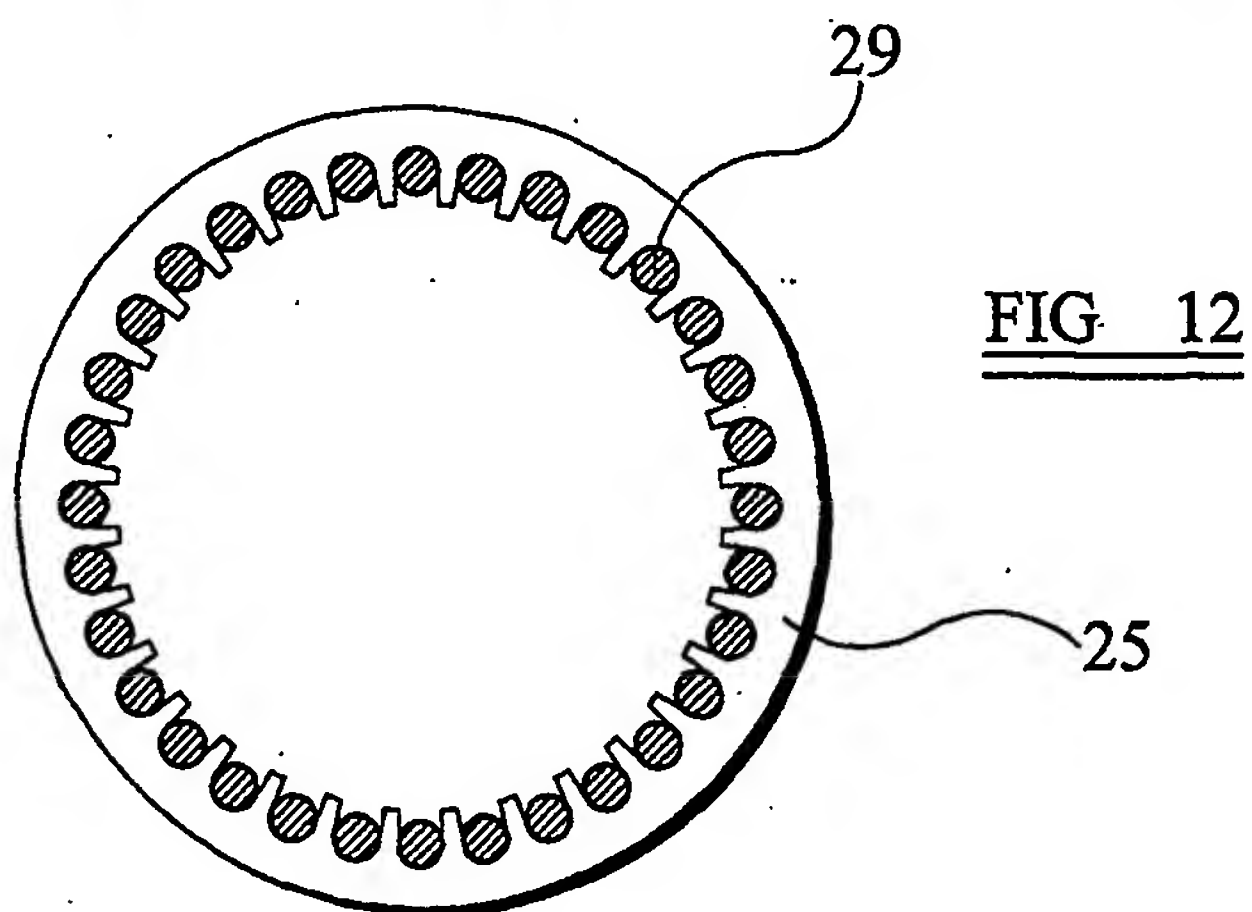
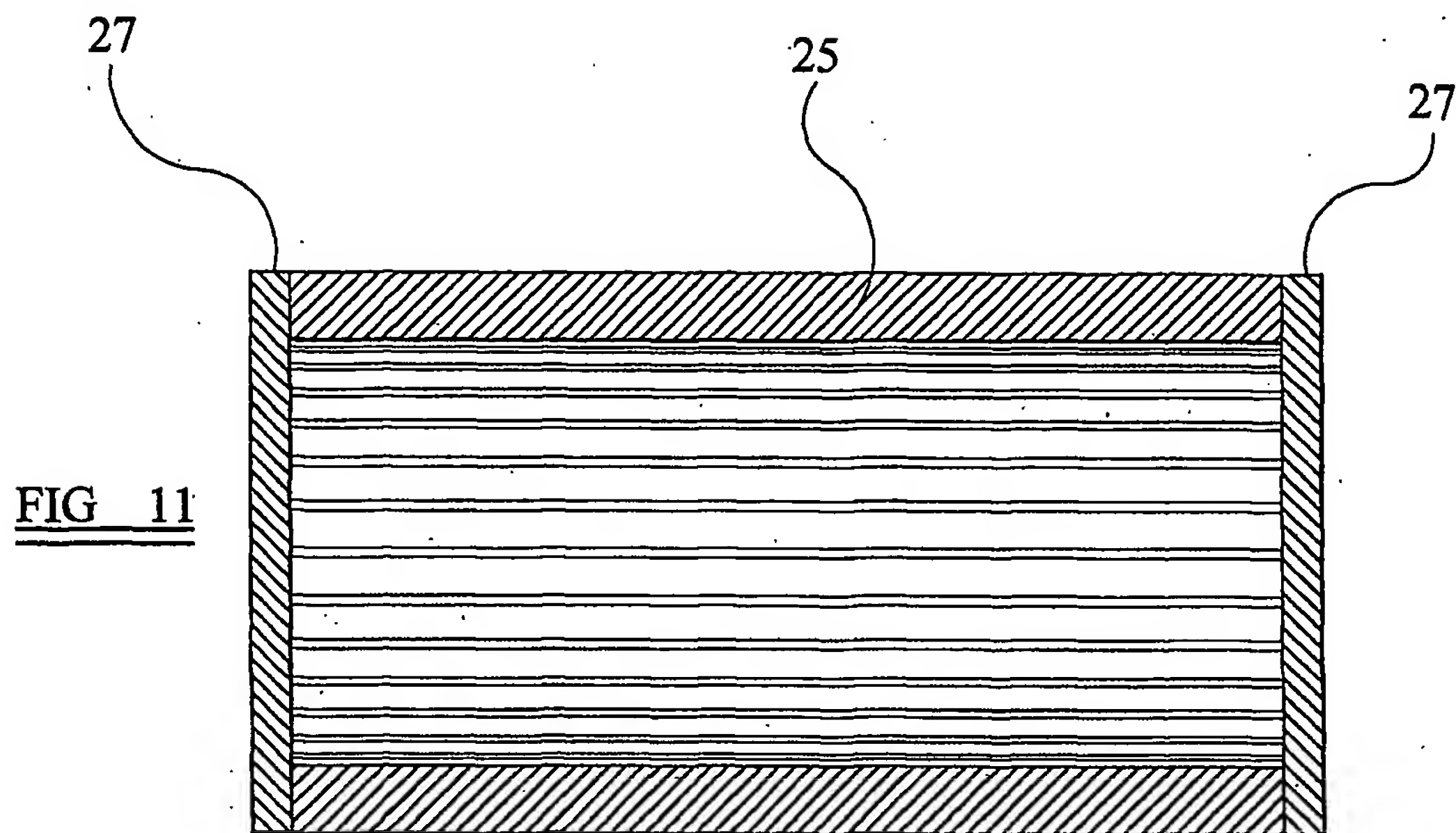
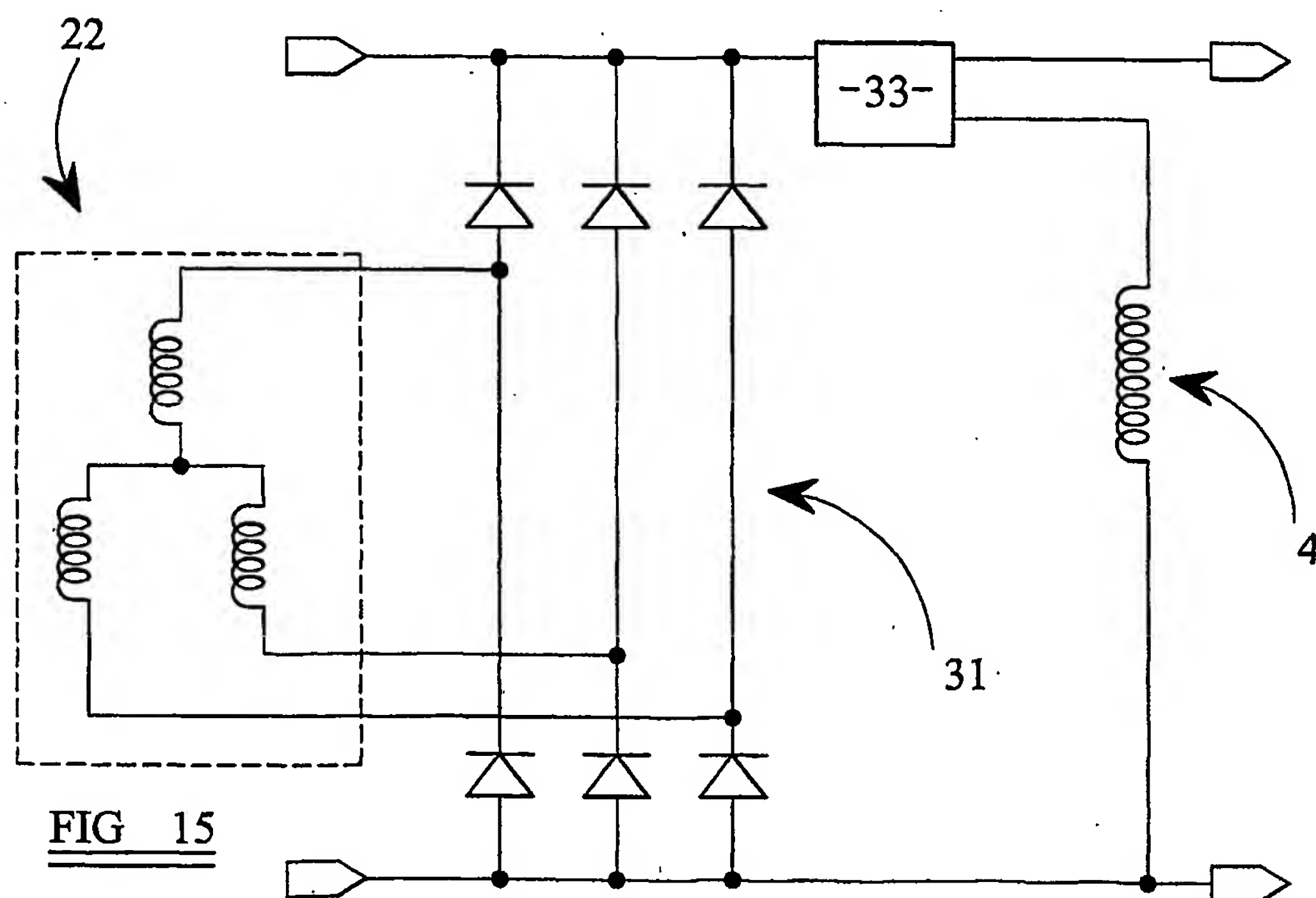
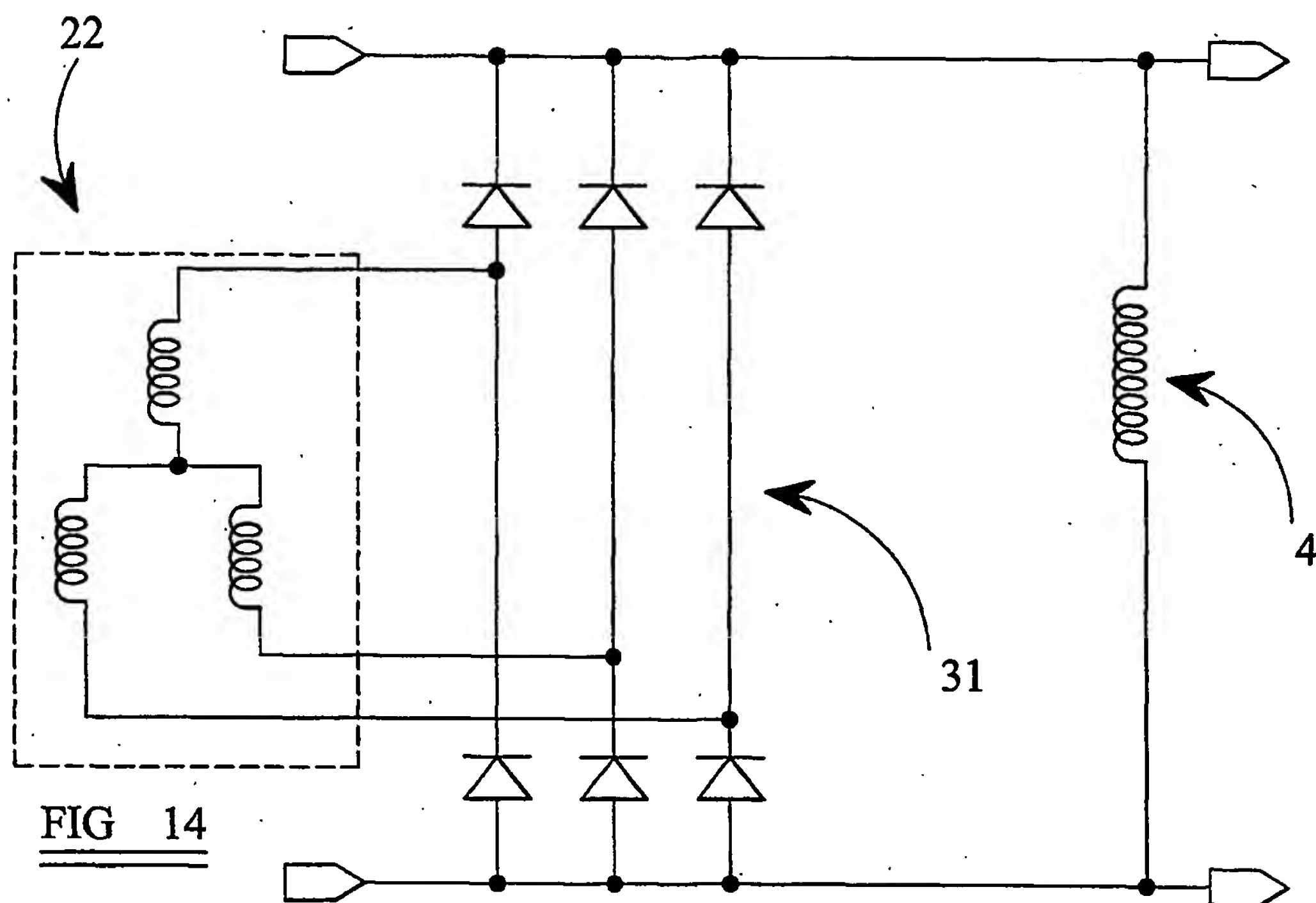


FIG 10







# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 02/01990

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H02K49/04 H02K16/02 H02K7/18 H02K17/34 E21B41/00  
E21B7/06 E21B17/02 F04D29/66 F04D13/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H02K E21B F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 713 567 A (FEY RAINER ET AL) 15 December 1987 (1987-12-15) the whole document ---	1-33
A	EP 0 520 733 A (CAMCO DRILLING GROUP LTD) 30 December 1992 (1992-12-30) column 9, line 56 -column 10, line 12 column 11, line 7 -column 12, line 33 figure 3 ---	1-33
A	EP 0 728 908 A (CAMCO DRILLING GROUP LTD) 28 August 1996 (1996-08-28) column 8, line 48 -column 11, line 33 column 12, line 53 -column 13, line 41 figures 4,5 -----	1-33

☐ Further documents are listed in the continuation of box C.

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Date of the actual completion of the International search

16 August 2002

Date of mailing of the international search report

23/08/2002

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International Application No

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